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INVESTIGATION OF THE MECHANICAL PROPERTIES AND CHARACTERISTICS OF SEVERAL ELECTRODEPOSITED METALS ON A FLEXIBLE PLATE OF HIGH CARBON STEEL

By Clyde R. Stewart

Ames Aeronautical Laboratory
Moffett Field, Calif.

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PURPOSE OF INVESTIGATION

Aerodynamic calibration and physical measurement have shown that the flexible steel plates which form two walls of the throat and test section of the 1-by 3-foot supersonic wind tunnels have surface irregularities of great enough magnitude to cause sizable flow disturbances.

Since some of the surface irregularities are as large as 0.020 inch, it was felt that simply remachining the 0.250-inch-thick steel plates would not be advisable for several reasons, one reason being that thinning the plates unevenly (0.020 to 0) would result in a nonlinear variation in thickness of 8 percent which would result in a nonuniform radius of curvature. Another objection to remachining is that once the plates are thinned, any further correcting or refinishing of the plates is made extremely marginal, if not impossible from a strength standpoint.

Thus it was decided to attempt to increase the thickness of the flexible plates by the electrodeposition of some suitable metal on the steel; then to machine the plates to obtain a flat, smooth surface while at the same time retaining the original thickness of 0.250 inch. This investigation of electrodeposited metals was therefore begun, the aim being to find an electroplating material that would meet the following requirements:

(a) Must be capable of being deposited up to 0.030 inch thick
(b) Must have good machining qualities
(c) Must not creep under a prolonged bending stress of 70,000 psi in basic steel
(d) Must not work harden excessively
(e) Must not develop surface cracks from repeated reversals of bending stress
(f) Must have no serious reduction in values of mechnical properties throughout temperature range 0° to 150° F
(g) Must have a Brinnel hardness above 50
(h) Should have a low modulus of elasticity in order to keep to a minimum the variation in moment of inertia of the basic plate
(i) Must have perfect adhesion to the basic steel, preferably without any "in-between" plate such as copper
(j) Must not oxidize or corrode in air
(k) The electroplating process must not reduce seriously the tensile, compressive, or endurance limits of the basic steel
(l) Must be readily available commercially

MATERIALS TESTED

The electrodeposited metals that were investigated are the following:

(a) Brass
(b) Cadmium
(c) Chromium
(d) Copper
(e) Nickel
(f) Silver
(g) Zinc

Lead and tin were also proposed for this investigation, but were rejected for being too soft (Brinnel No. 4 and 14, respectively), and for creep under moderate stress at room temperature.

Also tested along with the electrodeposited metals was a brush-on type of phenolic plastic coating called Phenoplast.

TEST SPECIMEN

Each test specimen was as nearly as possible a duplication of the flexible nozzle plates. A typical specimen was made of A.I.S.I. 4140 steel heat treated to Rockwell C-30 (minimum tensile strength 140,000 psi), and its surfaces were ground to rms 32. It was 24 inches long by $1\frac{1}{2}$ inches wide by 0.250 ± 0.001 inch thick.

TEST PROCEDURE

The material being tested was applied 0.005 inch thick by 10 inches long on both sides at one end of the test specimen, and 0.010 inch thick by 10 inches long on both sides at the other end of the test specimen - except where otherwise specified.

The test itself consisted of the following steps:

(a) Zyglo test to check for surface cracks
(b) Knoop hardness test at each end of specimen
(c) Micrometer measurement of thickness at 1-inch increments along length of specimen
(d) 1000 bend reversing cycles at 70,000 psi stress (Note: 1 cycle = 2 stress reversals)
(e) Repetition of steps (c) and (d) until 6000 cycles were completed
(f) Increase stress to 95,000 psi for 1000 cycles
(g) Repetition of steps (c) and (f) (Note: Total of 16,000 reversals based on 3 reversals per day, 5 days per week, 50 weeks per year for 20 years)
(h) Repetition of step (b) on end just tested
(i) Reversal of specimen, end for end
(j) Repetition of entire cycle (steps (b) through (h))
(k) Zyglo test to check for surface cracks.

TEST SET-UP

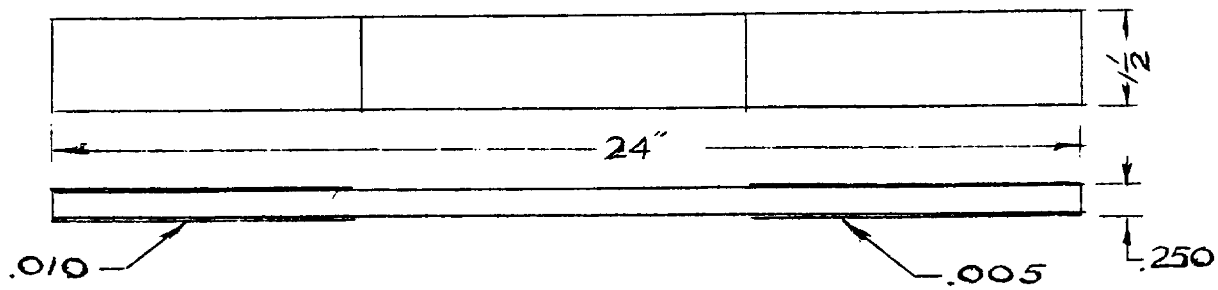

FIG. I TYPICAL TEST SPECIMEN

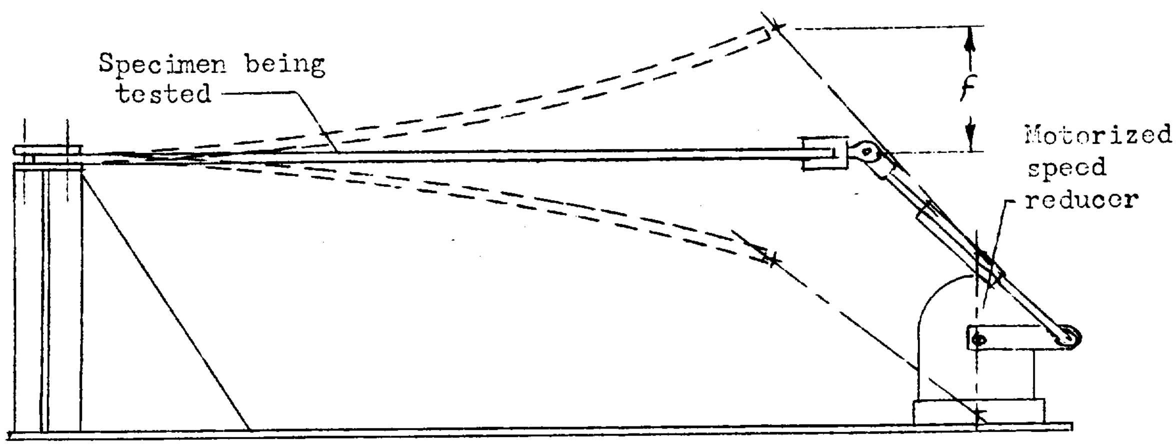

FIG. II TEST FIXTURE

DEFLECTION REQUIRED (f)

$$f = \frac{S l^2}{3Ec}$$

S = stress (psi)
l = 23.75 in.
E = 30,000,000 (psi)
c = 0.125 in.

TO PRODUCE STRESS = 70,000 psi

$$f = \frac{7 \times 10^4 \times 23.75 \times 23.75}{3 \times 3 \times 10^7 \times 0.125}$$

$$f = 3.5 \text{ in.}$$

TO PRODUCE STRESS = 95,000 psi

$$f = \frac{9.5 \times 10^4 \times 23.75 \times 23.75}{3 \times 3 \times 10^7 \times 0.125}$$

$$f = 4.75 \text{ in.}$$

RESULTS

Results of each test phase for each specimen tested are tabulated in Table I, together with the mechanical properties of each metal used as an electrodeposited coating.

Brass: Brass fulfilled all the requirements with the exception of being easy to deposit. It is, in fact, very difficult to deposit any heavier than 0.0005 inch of brass, due to pitting and uneven deposition using a normal solution and procedure.

Cadmimum: Cadmium is relatively easy to deposit, but when it is used for engineering purposes (i.e., heavy deposits to fill in worn or mismachined parts), great care must be used to insure a high degree of adhesion. In addition to being too soft to be easily machined, both the baked and the unbaked specimens developed bad surface cracks and checks, and both showed signs of creep.

Chromium: Chromium plating inherently causes embrittlement of the base metal; this is especially true of a high carbon steel base, and in this case the embrittlement was severe enough to cause failure of the test piece after 5200 cycles. Chromium is too hard to machine with standard machine tools, and so must be ground to the desired shape or thickness. Also, before failing, the test specimen had many bad cracks on its surface.

Copper: Copper filled most of the requirements very well; however, it did develop minute surface cracks, work hardened considerably, and, of course, oxidized in air.

Nickel: Nickel proved to be the best all around material in regard to meeting the requirements. The only exception is its relatively high modulus of elasticity ($24\text{-}27 \times 10^6$). Upon completion of the bend reversing test, the nickel specimen was given a similar test of 1800 cycles at 0° F in the stratosphere chamber; again the results were good. In addition, a piece of pure nickel was submerged in mercury for 72 hours at room temperature, after which time no amalgamation was evident.

Silver: Silver work hardened considerably more than any of the other metals tested. Cracks and checks developed on the surface, and there was evidence that the plating had yielded to plastic flow.

Zinc: Zinc was undoubtedly the least desirable of the metals tested. It yielded to plastic flow quite readily, became brittle below 70° F, and developed severe surface cracks.

Plastic Coating: A phenolic-type plastic called Phenoplast was applied to a typical steel test specimen and given the complete bending test. However, it was found that this coating is extremely difficult to apply smoothly, either by brushing or spraying; it is next to impossible to machine or hand finish; and it is dimensionally unstable.

DISCUSSION

Certain generalizations may be drawn from the experience gained through this investigation regarding the ability of electroplating to meet specific requirements.

(a) The adhesion of electrodeposits to a base metal is a function of the plating technique and is independent of the type of metal being deposited.

(b) The tensile strength, hardness, density, Young's modulus, etc., of any electrodeposit from any given type plating bath may be varied over a wide range simply by changing the pH (acidity), temperature, or current density of the bath.

(c) The electrodeposition of any metal on high carbon steel will cause embrittlement of the steel in degrees varying from severe embrittlement due to chromium plating to very slight embrittlement due to copper plating. The degree of embrittlement of the base metal due to any certain metal being deposited increases with an increase in plating time. This condition can be eliminated in part by baking the plated piece from 2 to 5 hours at from 300° to 500° F.

ENGINEERING ADVICE

The Electrodeposition Section of the National Bureau of Standards was contacted regarding this plating problem. They strongly recommended nickel plating as being the best adapted to our needs. They also suggested the type of nickel bath to use, the current density, and the preplating treatment in order to obtain the most ductile nickel deposit. (National Bureau of Standards letter to Ames dated November 22, 1949; mail listing November 28, 1949, No. 45).

EFFECT OF PLATING

Since both the depth and width of the plating after machining will vary nonuniformly throughout the length of the flexible plates, it is impossible to predict accurately the effect of the plating on the radius of curvature (or slope) of the plates. However, the worst case would be where a radius of 35 inches is considered; this amounts to a bending stress of 70,000 psi. Considering the longest span between two lugs (2.5 inches), and assuming the plating to be 0.020 inch of nickel over the full 12-inch width or a total plate thickness of 0.270 inch, we find a deflection of 0.0149 inch as compared to a deflection of 0.0186 inch for unplated steel

0.250 inch thick. This amounts to a change of 20 percent in radius of curvature. However, this does not take into account the effect of the lugs or their uneven spacing, nor the effect of the cadmium plating on the lower surface of the plates, nor the good possibility that the flexible plates are not of constant thickness to begin with - all of which would tend to decrease the change in curvature due to plating.

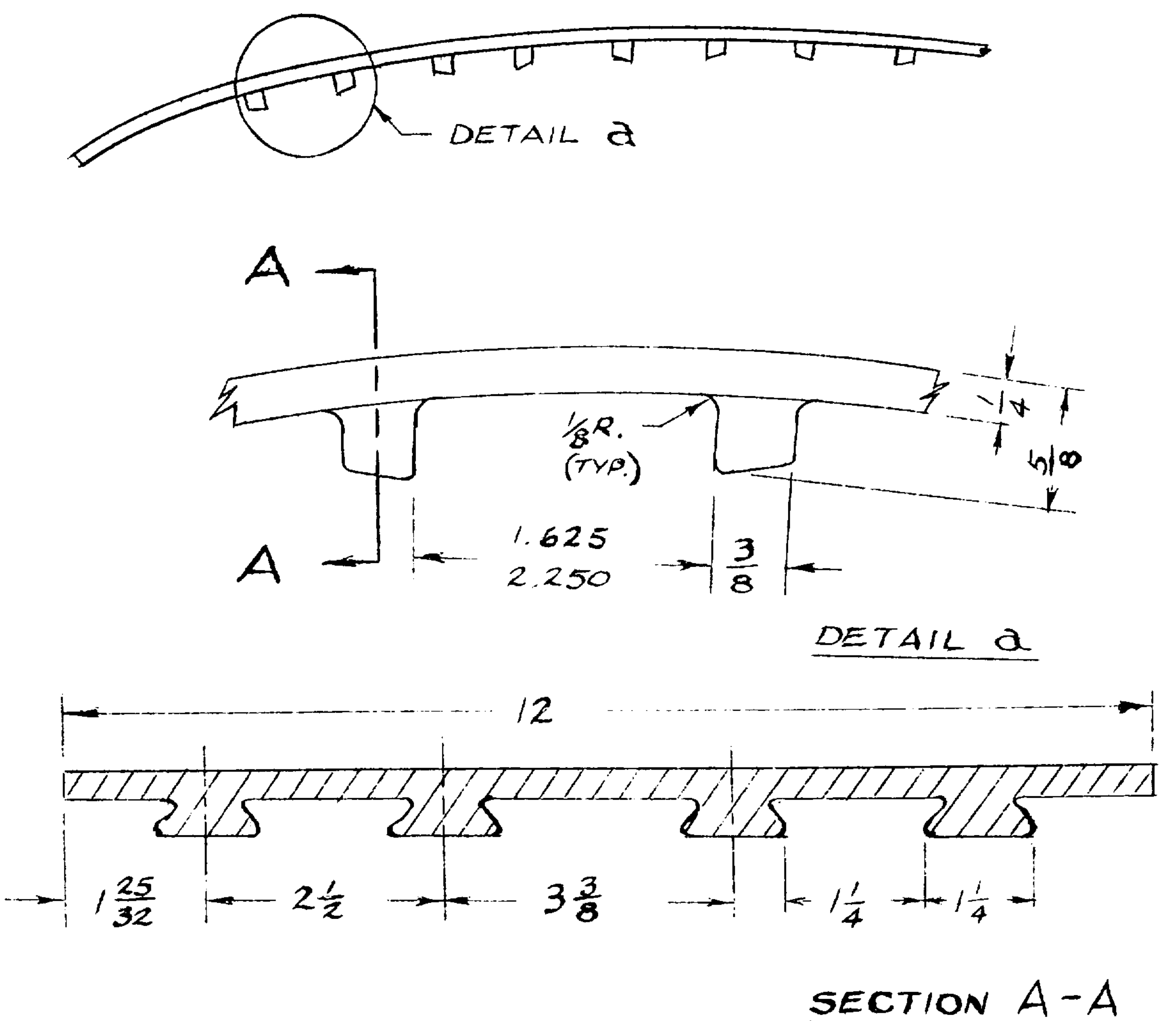

FIG. III FLEXIBLE PLATE

CONCLUSIONS AND RECOMMENDATIONS

As a result of this investigation, certain conclusions became apparent:

(a) Either nickel or brass plating would be a satisfactory answer to this problem from a mechanical and aerodynamic standpoint.

(b) Nickel plating would be the only satisfactory answer from a practical standpoint, since brass plating of 0.030-inch thickness would require much research work and involve a great deal of expense. This conclusion is borne out in a letter from National Bureau of Standards to Ames dated December 16, 1949; mail listing December 21, 1949, No. 42. It is therefore recommended that nickel plating be used to correct the flexible nozzle plates, using the procedure and plating bath composition suggested by the National Bureau of Standards.

COMMERCIAL PLATING PLANTS

Through contact with the International Nickel Co. the following plating concerns were recommended as reliable and as being equipped to handle these large plates:

1. Bone Engineering Co., Glendale, Calif.
2. Plating Engineering Co., Milwaukee, Wis
3. Chromium Corp., Chicago, Ill.

REFERENCES

1. A.S.T.M. Standards, 1946, Part I - B.
2. Kent, Mechanical Engineers Handbook 7 - 07, 17 - 83, 21 - 56.
3. Metals Handbook, 1939, p. 1101.
4. Blum and Hogaboom, Principles of Electroplating, 2nd Ed., McGraw Hill Book Co., 1930 .
5. Simonds: Finishing of Metal Products.
6. Journal of Research, August 1949, National Bureau of Standards, Vol. 43, No. 2.

TABLE I

SUMMARY OF TEST RESULTS

PLATING OR COATING TESTED	PLATING BATH COMPOSITION	PLATED BY:	BAKED AFTER PLATING	PLATING THICKNESS	SURFACE CRACKS: BEFORE	SURFACE CRACKS: AFTER	PLATING HARDNESS (KNOOP NO): BEFORE	PLATING HARDNESS (KNOOP NO): AFTER	CREEP: AMT IN.	CREEP: CYCLES	CREEP: IN. FROM END
BRASS	NOTE #1	AA PLATING WKS. S.F.	NO	.00[illegible]	NO	NO	195	199	0	[illegible]	0
				[illegible]	NO	NO	219	222	.00	[illegible]	3.0
CADMIUM	STD	NACA	NO	[illegible]	NO	YES	[illegible]	[illegible]	.00	[illegible]	3.0
				[illegible]	NO	YES	25	[illegible]	.00	[illegible]	0.5
CADMIUM	STD	NACA	YES 350°F	[illegible]	NO	YES	25	[illegible]	[illegible]	[illegible]	1.0
				[illegible]	NO	YES	24	[illegible]	[illegible]	[illegible]	[illegible]
CHROMIUM	STD	NACA	NO	[illegible]	NO	YES	950	962	0	[illegible]	1.0
				[illegible]	NO	YES	910	918	.00	[illegible]	1.0
COPPER	STD	NACA	NO	[illegible]	NO	YES	105	153	0	[illegible]	0
				[illegible]	NO	YES	165	161	0	[illegible]	0
NICKEL	HIGH pH WATTS NOTE #2	NACA	YES 350°F	[illegible]	NO	NO	225	230	0	[illegible]	0
				.010	NO	NO	250	258	0	[illegible]	0
SILVER	STD	NACA	NO	.005	NO	YES	43	72	0	[illegible]	1.0
				.010	NO	NO	45	75	0	[illegible]	0
ZINC	UNKNOWN	AA PLATING WKS. S.F.	NO	.005	NO	NO	49	62	0	[illegible]	0
				.010	NO	YES	40	57	[illegible]	[illegible]	0
PLASTIC	—	NACA	—	.005	NO	NO	—	—	[illegible]NUAL [illegible]ING & [illegible]SICAL [illegible]BILITY.		

PLATING OR COATING TESTED	NEAREST EQUIPPED PLATING CONCERN	EMBRITTLEMENT OF BASE METAL	ADHESION OF PLATING	REMARKS	TENSILE STRENGTH (KIPS)	YIELD STRENGTH (KIPS)	E $\times 10^6$	BRINELL HARDNESS NO	LINEAR COEFF OF EXPANSION (in/°F)
BRASS	NONE	SLIGHT	EXCELLENT	SEE R[illegible]SULTS	22-125	15-40	15-20	40-240	.0000167 TO .0000214
CADMIUM	PACIFIC RUSTPROOF CO.-OAKLAND	MODERATE	EXCELLENT		10-12	—	10	21-24	.00001755
CADMIUM	SAME	MODERATE	EXCELLENT	VISIBLE CRA[illegible]NG @ 3500 CYCLES / VISIBLE SE[illegible] CRACKING @ < 1000 [illegible]CLES	10-12	—	10	21-24	.00001755
CHROMIUM	INDUSTRIAL HARD CHROME PLATING CO. EMERYVILLE	SEVERE	FAIR	TEST BAR [illegible]LED @ 5200 CYC[illegible]	—	—	—	500-1150	.00000378
COPPER	NONE	SLIGHT	EXCELLENT	SURFAC[illegible] CRACKS VERY [illegible]NUTE	20-30	10-25	16	105	.00000926
NICKEL	BONE ENGINEERING CO. GLENDALE	SLIGHT	EXCELLENT	MACHIN[illegible] WELL - TAKES [illegible]RROR FINISH	42-125	21-115	24-27	75-200	.00000566
SILVER	SAME AS CHROME	SLIGHT	EXCELLENT	CRACK[illegible] APPEARED ON TH[illegible] END BUT NOT O[illegible] THICK.	41-51	—	10.3-11.2	42	.00001067
ZINC	NONE	MODERATE	EXCELLENT	CRACK[illegible] BADLY, BRITT[illegible] BELOW 70°F	8-35	12-28	12	39	.00001659
PLASTIC	—	NONE	FAIR	SEE [illegible]ESULTS	REF. KENT 1-05 & 21-56				

NOTE 1: COPPER 3.4[illegible] pH 10.5
ZINC [illegible] 9[illegible] 5 VOLTS @ 120°F
FREE CYANIDE 2.5 NO AGITATION

NOTE 2: NICKEL SULFATE 32 OZ/GA[illegible] pH 5.6
NICKEL CHLORIDE 6 OZ/GA[illegible] TEMP 120°F
BORIC ACID 4 OZ/GA[illegible] CURRENT DENSITY 20-25 AMP/FT.²

CRS [illegible]